# TEACHING AND LEARNING ABOUT THE BIOLOGICAL EVOLUTION: CONCEPTUAL UNDERSTANDING BEFORE, DURING AND AFTER TEACHING

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## ABSTRACT

This study is part of a project with the main purpose of developing a teaching-learning sequence that enables the students to construct a scientific model of the biological evolution. Another purpose is to document the students' conceptual development. Our theoretical background is the model of conceptual change initially proposed by Posner et al (1982). Here we focused on two key concepts in evolution – "variation" and "natural selection". The development and the long-term retention of these concepts among Swedish students (16 – 19 years old) were studied. The students' prior knowledge was investigated by a pre-test before teaching. During the teaching period some students were interviewed about these concepts, and small group discussions about the same concepts were videotaped. Approximately a year after teaching the students was given a delayed post-test. The majority of the students abandoned their prior ideas of strive and need, and adopted a more scientific view of these concepts. This was evident both in the interviews and in the post-test. The conceptual development of the interviewed students is discussed in the paper.

## BACKGROUND

During the last two decades several studies have shown that students of different ages, from different cultures and different educational systems, have difficulties understanding the theory of biological evolution (Deadman and Kelly, 1978; Brumby, 1984; Clough and Wood-Robinson, 1985; Lawson and Thompson, 1988; Greene, 1990; Pedersen, 1992), and that the students' understanding did not improve much after traditional teaching (Halldén, 1988; Bishop and Anderson, 1990; Bizzo, 1994; Demastes, Settlage and Good, 1995). Some specially designed teaching strategies gave better results, e.g. the explicit comparison of different evolutionary ideas in group-discussions (Jiménez-Aleixandre, 1992), teaching with a historical approach (Jensen and Finley, 1995; 1996) and the use of certain reading materials (Peled, Barnholz and Tamir, 1998). However, the long-term effect of these strategies has not yet been investigated.

The conceptual change model for learning, initially proposed by Posner, Strike, Hewson and Gertzog (1982), has been widely used not only to describe learning in science but also as a guideline for designing teaching (Hewson, Beeth and Thorley, 1998). According to the original formulation of the model, learning is described as a rationally driven and logical process. There are four prerequisites for conceptual change to occur. The learners must experience dissatisfaction with their existing conception, and any new conception must be intelligible, plausible and fruitful. After criticism of being overly rational, the model has been revised and extended, so that the importance of social and affective aspects now is recognised (Strike and Posner, 1992, Duit and Treagust, 1998). We place the construction of knowledge in the mind of the individual, but this construction can be positively promoted in different social interactions. Demastes, Good and Peebles studied students' conceptual change in the content area of evolution (1995, 1996). They described some patterns of conceptual restructuring that, according to their opinion, do not conform to the conceptual change model, and concluded that further research in this field is needed.

## PURPOSE AND QUESTIONS

The study presented in this paper is part of a project with the main purpose of developing a teaching-learning sequence that enables the students to construct a scientific understanding of the biological evolution. The aim of this study is to document the students' conceptual development, by investigating their understanding before, during and after teaching. Special attention is paid to the way students articulate their understanding in different situations, orally or in writing. We focus on two key concepts in evolution, namely "variation" and "natural selection". A number of frequently occurring alternative understandings of these concepts are known, e.g. the ideas of need and strive as forces in evolution, the idea of individual adaptation in the context of evolution and the inability to see the importance of the variation within a population. This paper pays attention to tests, small group discussions and interviews around two multiple-choice problems concerning the origin of variation and natural selection and is designed to assess the effect of instruction both in a short and a long perspective.

The research questions addressed in this paper are:

- How do the students understand "the origin of variation" and "natural selection"?
- How does the students' understanding of these concepts change during teaching?
- Will these changes persist for a longer period?
- Are the students aware of any conceptual change themselves?

## METHODS

### Design of the study

The overall design of the study is shown in figure 1. A pre-test was performed prior to a four week teaching-learning sequence on biological evolution. During the teaching-learning sequence data was collected by interviews and videotaped small group discussions. Almost a year after the teaching the students were given a delayed post-test.

| February 1999 | March 1999 | April 1999 | February-March 2000 |
| --- | --- | --- | --- |
| | Teaching-learning sequence | | |
| Pre-test | Small group discussion 1<br>Interview 1<br>Small group discussion 2<br>Interview 2 | Written exam | Delayed post-test |

**Figure 1.** The design of this study.

### The teaching-learning sequence

Our teaching-learning sequence of biological evolution is intended for students in the upper secondary school, taking a high-level biology course (Biology A). This course comprises 50 hours of teaching and covers mainly ecology, ethology and evolution. Evolution is strongly emphasised in the syllabus of this course (Skolverket, 1994), and we used 15 out of 50 hours exclusively for evolution. By the use of a pre-test, the teacher was made aware of the preconceptions held by his students. These preconceptions were also presented, at a group level, to the students, and served as a starting point for discussions. The purpose of these strategies was to allow the students to develop a metacognitive perspective on their understanding of evolutionary concepts and to elicit cognitive conflicts. In order to further facilitate conceptual change, the teaching-learning sequence gave the students the possibility to talk and discuss a lot, both in small groups with appropriate problems and in full class with the teacher as scientific leader.

**The students**

The participants in this study were grade 11 students attending the Natural Science Programme. The school is located in a municipality close to Göteborg, where the vast majority of the population are middle class ethnical Swedes. The Natural Science Programme has a reputation of being highly demanding, so the students in this study can be described as well motivated and gifted. Two groups with a total of 49 students (16-19 years old), who were taught by one of the authors (MH), were followed during the teaching-learning sequence on biological evolution.

**The tests**

Prior to the teaching-learning sequence the students were given an unprepared pre-test about evolution. This test consisted of nine problems, some open-ended but mostly multiple-choice. The authors of this paper designed the two test items, which are discussed here. The alternatives were chosen according to common alternative conceptions held by students (figure 2). The pre-test was distributed over the Internet, so the students answered the test on computers and their answers were submitted directly to our database.

Since we are particularly interested in long-term retention, the students were given a post-test approximately one year after the teaching sequence. This delayed post-test was essentially identical to the pre-test.

Problem 4

Throughout time living organisms have developed a variety of different traits. What is the origin of this enormous variation?

1. The traits arose when they where needed.
2. Random changes in the gene pool of the organisms.
3. Living organisms strive to develop.
4. Great variation is needed in order to get balance in nature.

Problem 5

Which one of the following alternatives does best explain changes in a population with time?

1. Some individuals are better at reproducing than others.
2. Some individuals starve to death, while others survive by moving to new places.
3. Organs and structures that are needed evolve.
4. Individuals can adapt to survive.

**Figure 2.** The two multiple-choice problems in the pre-test, which were discussed in the interviews, and also used in the delayed post-test.

### The interviews

In order to follow the students' conceptual development during the teaching period, some students were interviewed about the concepts "variation" and "natural selection". One of the main issues that were brought up during the interviews was the students' thoughts about the different alternatives in the test problems (no. 4 and 5 respectively). About a week before the first interviews the teaching dealt with mutations and other random changes in the gene pool. Twelve students were interviewed about variation and were chosen according to their answers to one of the pre-test problems (no. 4) in a way that all alternatives were represented. Two weeks later 35 students were interviewed about the concept of natural selection. On this occasion all available students in the two groups were interviewed. The interviews were performed with one student at a time, they were structured and followed an interview guide. All interviews were audio taped and transcribed word for word.

In addition, small group discussions, with 4-5 students, regarding the same concepts were performed before corresponding interview. In these discussions the students were left without any teacher or researcher, but the discussions were videotaped and transcribed.

## RESULTS

### The origin of variation

During the interviews on the origin of variation the students (n=12) were asked to comment on the four different alternatives that were given in problem 4 in the pre-test (se figure 2). The comments were categorised in three levels; agree, partly agree and disagree (table 1).

**Table 1**. Categorisation of the students' comments, to problem 4 in the pre-test. (n=12, some students did not comment on all alternatives.)

| Alternative | Agree | Partly agree | Disagree |
|---|---|---|---|
| 1. "Need" | 0 | 8 | 2 |
| 2. "Mutation" | 7 | 4 | 0 |
| 3. "Strive" | 4 | 2 | 6 |
| 4. "Purpose" | 8 | 0 | 4 |

- Alternative 1: "The traits arose when they where needed"

A majority of the students (8 of 12) agreed partly and expressed different reasons in favour to this alternative. Some of these students clearly distinguished between the origin and the survival of new traits, but still considered "need" to be an acceptable explanation to the origin of variation e.g.:

> *S7: … they arise, not exactly because they were needed but those who were needed were preserved, and that is a bit the same thing.*

- Alternative 2: "Random changes in the gene pool of the organisms"

Seven agreed totally and four students partly agreed, e.g.:

> *S16: I think it is a bit like number two with random change … if webbed feet arose as a trait and then was needed, it was preserved.*

Here the student referred to the survival of the trait, which he called "need".

- Alternative 3: " Living organisms strive to develop."

Six students agreed with this with two different ways of arguing. Four used anthropomorphic reasoning while referring to man as example (e.g. S34) and two used the concept of adaptation in the sense of individual adaptation.

> *S34: Of course you strive to develop; you don't want to stand on the same spot all your life.*

- Alternative 4: "Great variation is needed in order to get balance in nature."

Most students agreed, eight of the interviewed. It is likely that most of these accept the statement that nature needs variation.

At the end of the interview the students were asked to choose which of the four alternatives they preferred this time. Eight of the students had changed their alternative from the pre-test, seven of those to the more scientific view (random genetic change). The reasons they claimed for change was the teaching (7 students), the textbook (3 students) and/or own thoughts (3 students). Most of those who articulated reason did not show any difficulty in changing opinion; it was simply due to teaching.

**The concept of natural selection**

About a week before these interviews about natural selection (n=35), the students had been taught about natural selection and had discussed this concept in small groups. During these interviews the students were asked to comment on the four different alternatives to problem 5 (figure 1). The comments were categorised in three levels; agree, partly agree and disagree (table 2).

**Table 2**. Categorisation of the students' comments, to problem 5 in the pre-test (n=35).

| Alternative | Agree | Partly agree | Disagree |
|---|---|---|---|
| 1. "Reproduce" | 20 | 12 | 3 |
| 2. "Move" | 24 | 9 | 2 |
| 3. "Need" | 7 | 9 | 19 |
| 4. "Adapt" | 14 | 5 | 16 |

- Alternative 1: "Some individuals are better at reproducing than others"

The majority of the students agreed or at least partly agreed to this alternative. Most students could see the connection between success in reproduction and population change. The other eight students did not:

> *S28: "Some individuals are better at reproducing than others" … perhaps they are, but …reproduction has nothing to do with change, I think.*

- Alternative 2: "Some individuals starve to death, while others survive by moving to new places"

All except two students agreed to some extent to this alternative. Many also showed that they realise that this is not the major explanation to evolutionary changes.

- Alternative 3: "Organs and structures that are needed evolve"

Seven students agreed with the statement. However, four of them used the term "need" in a way that suggests that they understood that evolution is not need-driven. The same thoughts were expressed among several of the students who partly agreed.

*S31: … Number three I think fits well. … Yes. ”Organs and structures that are needed evolve”. But a mutation has to occur for it to develop, it is nothing they have any influence on.*

- Alternative 4: “Individuals can adapt to survive”

About half of the students agreed or partly agreed to this alternative. The majority of them had not, at the time of interviews, understood the significance of the concept of adaptation. Several students still expressed their belief in individual adaptation as an evolutionary process. Only four students discussed adaptation in an evolutionary correct way.

At the end of the interview the students were asked to choose which of the four alternatives they thought was best this time. In the pre-test the majority of the interviewed students (75%) had chosen the alternative ”adapt”, but during the interviews many students showed a more scientific view of the concept, i.e. they choose the alternatives “reproduce” (47%) or “move” (26%).

The majority of the interviewed students had changed alternatives since the pre-test. Nine of them were aware of their change, and offered an explanation how their thoughts had changed. Another ten students could give some kind of explanation to their change, after being confronted with their choice in the pre-test. These 19 students were analysed especially regarding any signs of conceptual change of natural selection. Eleven of them seemed to be rearranging their conception of adaptation and three students remembered that they before teaching saw evolution as a need-driven process. The other five discussed their changed views about mutations, acquired traits and the enormously long time of biological evolution.

**The long termed retention**

Approximately one year after the end of the teaching-learning sequence the students performed a delayed post-test. The problems concerning the origin of variation and change in populations with time appeared in both pre- and post-tests.

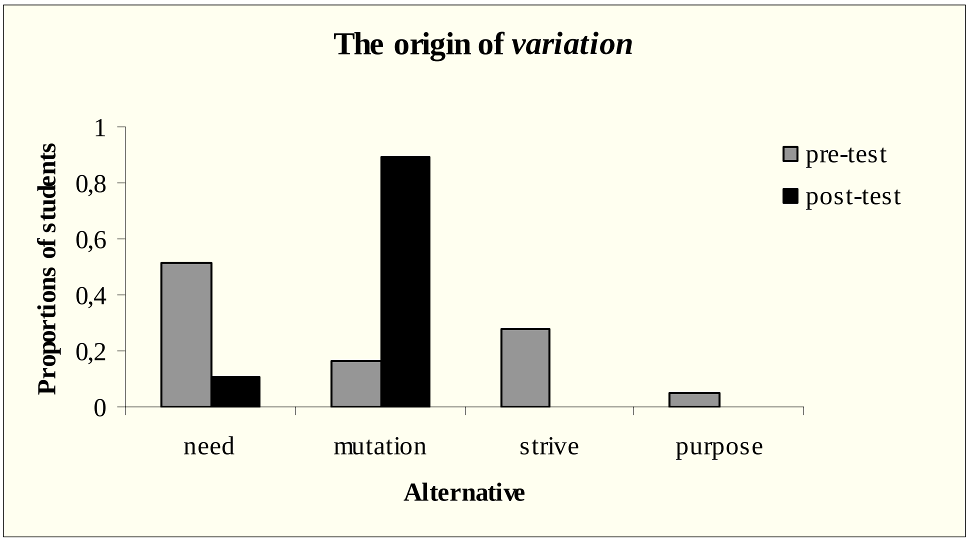


**Figure 3.** The proportion of students ($n_{pre}$=43; $n_{post}$=47) choosing the different alternatives to problem 4.

On problem 4 the students had totally abandoned the alternatives “strive” and “purpose” and almost everyone (89%) chose the “mutation” alternative (figure 3).

In the post-test 28% of the students chose the “adapt” alternative in problem 5 (figure 4). The alternative that teaching tried to support (“reproduce”) increased in proportion to 36% compared to 2% in the pre-test.

As judged by the results in the delayed post-test, the long-term retention of the teaching on students’ conceptions of “the origin of variation” and “natural selection” was good.

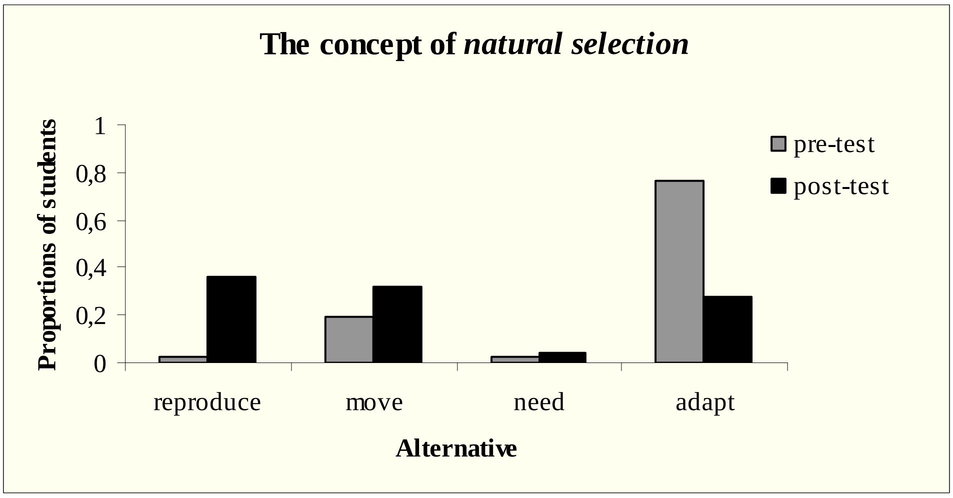


**Figure 4.** The proportion of students ($n_{pre}$=42; $n_{post}$=49) choosing the different alternatives to problem 5.

# DISCUSSION

This study confirms the results from several other studies, that there are a number of common alternative understandings regarding biological evolution. One of the major obstacles for a scientific understanding is the failure to recognise the existence of two separate processes in evolution (Bishop and Anderson 1985, 1990):

1. The appearance of traits in a population
2. The survival of such traits in a population over time

When it comes to the first of these processes, the students in this study seem to accept mutations as the ultimate source for new traits rather easily. And, as seen in figure 3, most students still accepted random mutations a year after teaching. In the interviews, several students expressed their doubts about the randomness in evolution. However, we also got the impression that when the students understood that evolution consists of several processes, of which only one is random, they accepted the randomness more easily.

The students in this study did not seem to have any problems with connecting natural selection to enhanced survival or to differences in survival, but a few students had difficulties in seeing reproduction success as necessary for population change. They saw variation in reproduction ability as a completely separate trait that had nothing to do with population change.

## The understanding of need and adaptation

In several studies students' use of the term "need", in the context of evolution, has been interpreted as if the students believe evolution to be a need-driven process (e.g. Bishop and Anderson, 1985; Demastes, Settlage and Good, 1995). This investigation shows, both in interviews and small group discussions, that some students can use this term and still have a sound understanding of the processes of evolution.

Using the term "need" this way does not contradict an understanding of the processes of evolution. It is used almost synonymous to "advantageous" or "beneficial". One could say that these students see the origin of variation as mutations but the survival of traits as a need-driven process, which is very close to the scientific view. This is an important finding, which must be paid attention to when studying students' conceptions of evolution.

It seems to be quite hard for the students to understand adaptation in the evolutionary manner. In spite of the fact that many students understood the word "adaptation" as something concerning the theory of evolution, few had acquired the evolutionary meaning of the word. This is obvious in this study and has also been shown in other studies (e.g. Bishop & Anderson, 1985; 1990; Bizzo, 1994).

## Signs of conceptual change

During the interviews it became clear that many students were struggling with capturing new concepts. Although most students chose the more scientific alternatives when they were forced to select, they were not so sure in their choices. As table 1 and 2 show many students could also see advantages in the less scientific alternatives. This is not only a sign of the ambivalence students experience when rearranging their concepts, but also illuminates the problem with making conclusions of students understanding on basis of multiple-choice problems.

Obviously the teaching made some students feel dissatisfaction with their existing concepts, for example adaptation, need-driven evolution and mutations. One of the students, who were rearranging her understanding of adaptation, explained that the evolutionary significance of the adaptation concept was more plausible than her old understanding. Another student talked of his prior understanding of evolution as a need-driven process and could give an example on what he thought would have happened if his prior thinking had been plausible.

> *S38: … if they needed a longer neck, they would get one.*

Later during the interview he was asked about why he had changed opinion:

> *S38: … after we have read about Darwin and talked about everything.*
> *I: Do you think it works only in school or do you think it is more plausible?*
> *S38: Yes, it actually is. … for otherwise I think we ought to have wings nowadays or something.*

These examples fit rather well with the conceptual change model (Posner et. al., 1982).

## IMPLICATIONS FOR TEACHING

We consider the conceptual change model to be a fruitful theoretical background for designing teaching. The results in this study are promising, especially regarding the long-term retention. However further research is desirable for comparing the outcome from this approach with "traditional" teaching.

Many students enter teaching with an understanding of evolution as one entity, a gradual adaptation process. We suggest that if teaching starts with separating the theory of evolution into two or more processes, it might become easier for the students to understand the randomness of mutations, the importance of reproductive success and the evolutionary significance of adaptation. Later on the teaching should help the students to capture a new entity of the theory of evolution, as natural selection working on inherited variation of traits in a population over time.

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